https://doi.org/10.17221/130/2023-HORTSCI

Endophytic *Streptomyces* extend the vase life of *Gerbera jamesonii* L. by modulating the antioxidant system and suppressing bacterial growth

Wen Lin, Xi Wei, Ying Li, Muhammad Imran Ghani, Xiaojing Hu, Xiaoyulong Chen**

College of Agriculture/College of Life Sciences, Guizhou University, Guiyang, P.R. China
International Jointed Institute of Plant Microbial Ecology and Resource Management in Guizhou University, Ministry of Agriculture, China Association of Agricultural Science Societies, Guiyang, P.R. China
Guizhou-Europe Environmental Biotechnology and Agricultural Informatics Oversea Innovation Center, Guizhou Provincial Science and Technology Department, Guizhou University, Guiyang, P.R. China

**Corresponding authors: gdhxjyy@163.com; chenxiaoyulong@sina.cn*

Citation: Lin W., Wei X., Li Y., Ghani M.I., Hu X.J., Chen X.Y. (2025): Endophytic *Streptomyces* extend the vase life of *Gerbera jamesonii* L. by modulating the antioxidant system and suppressing bacterial growth. Hort. Sci. (Prague), 52: 224–236.

Abstract: Gerbera flowers are the best-selling cut flowers worldwide owing to their attractive appearance. Nevertheless, one significant challenge for gerbera flowers is their relatively short vase life. Commercially, synthetic chemicals are used to prolong the vase life of flowers; however, they are not environmentally friendly, posing sustainability concerns. Therefore, we used different concentrations of the biocontrol spore suspension of *Streptomyces exfoliatus* FT05W and evaluated their effect on vase life, bacterial population, and different morphology and physiological indices of gerbera cut flowers, with the objective of determining the optimal concentration for maximum efficiency. The results revealed that all spore suspensions of *S. exfoliatus* FT05W (1×10^6 CFU mL) significantly extended vase life and were 4 days longer than the control. *S. exfoliatus* FT05W treatment also increased bottle life extension days, blossom diameter, and fresh weight, and maintained water balance. In addition, it decreased malondialdehyde (MDA) levels and relative electrolyte leakage (REL), leading to decreased oxidative stress. *S. exfoliatus* FT05W significantly increased antioxidant enzymes, including superoxide dismutase (SOD) activity, catalase (CAT) activity, peroxidase (POD) activity, soluble sugar (SS), and soluble protein (SP), compared to the control. Furthermore, it can effectively inhibit bacterial proliferation, resulting in a decline in colonies and a significant delay in the flower ageing process. The beneficial impacts of *S. exfoliatus* FT05W were most pronounced at a concentration of 1×10^6 CFU/mL. The findings of this research suggest that *S. exfoliatus* FT05W has great potential as a bio-fertiliser for cut flowers, as it is capable of addressing the challenges associated with flower cultivation.

Keywords: endosymbiotic actinomycetes; *Gerbera jamesonii*; postharvest floral longevity; physiological

Supported by the Natural Science Foundation of China (Grant No. 31701836), Guizhou Provincial Science and Technology Program [Grant No. 2019-1410; HZJD2022-001; GCC(2023)070] and Guiyang Science and Technology Bureau, China, Project Research and integrated demonstration on key technologies of introducing, expanding and supporting cultivation of new excellent varieties of grass flower [Project No. (2019)5-3].

https://doi.org/10.17221/130/2023-HORTSCI

Gerbera jamesonii L. is a perennial herbaceous plant belonging to the Asteraceae family, known for its large, vibrant flowers, striking colours, and popularity in the cut-flower industry, and has earned it a place among the world's top ten cut flowers (Gantait et al. 2011; Li et al. 2019). With ample flower size and a heavy head, gerbera is susceptible to microbial infections, ethylene production, and physiological changes, which can cause early flowering, stem bending, and petal loss, leading to a significant decline in its aesthetic appeal (Perik et al. 2012; Perik et al. 2014).

Gerbera, which is prone to early wilting and a bent neck, frequently experiences a decline in vase life due to reduced water uptake in cut flowers. This can be attributed to various factors, such as physiological or stem blockage caused by microbial growth within the vascular bundle, resulting in the formation of air bubbles (Mohammadi et al. 2020). Cut flowers can experience a negative water balance due to obstruction of xylem vessels, which can be caused by changes in water uptake and surface evaporation. Vascular bundle occlusion can occur in various ways, including through the proliferation of pathogenic bacteria and other microorganisms. However, it is important to note that the types of bacteria found at the stem ends can differ among flower species (Balestra et al. 2005). Some bacteria possess the capability to secrete extracellular virulence factors, including pectic enzymes and harmful substances that generate ethylene or other hormones. These factors are responsible for causing damage to the structure of flower scapes and accelerating their senescence. However, there are bacteria that may have a beneficial impact on the longevity of flowers or have no apparent effect (Naing, Kim 2020).

Li et al. (2012) found that four predominant bacterial species in the stem ends of cut roses significantly impacted their vase life and water-absorbing ability. Specifically, when the initial concentration of these bacteria in the vase solution reached 10^8 colony-forming units per mL (8 $\log_{10}$ CFU/mL), the vase life of the roses was greatly reduced, and their water uptake was diminished. Naing et al. (2017) also demonstrated that adding 10^7 CFU/mL of *Enterobacter cloacae* to the vase solution extended the vase life of cut 'Omega' carnations by 3 days compared to the control group. The influence of bacteria present in the stem ends and vase water on the vase life of cut gerbera flowers remains unclear. According to Schouten et al. (2018), the effect of bacteria on cut gerbera flowers varies depending on the specific bacterial genotype. Therefore, it is essential to study individual bacterial strains in vase water to improve our understanding of their role in reducing the vase life of gerbera flowers.

Cut flowers are often dipped in vase solutions to maintain their quality and extend their vase life. These solutions were formulated to prevent the spread of pathogenic microorganisms within the vascular bundles (Acharyya et al. 2013).

Many studies have explored methods for preserving cut gerbera flowers, primarily focusing on using plant growth regulators, such as gibberellic acid (GA_3), benzyl adenine (BA), and salicylic acid (SA) (Danaee et al. 2011; Mehdikhah et al. 2016; Shabanian et al. 2019). Additionally, chemicals such as chlorpromazine (Karras et al. 2007), silver thiosulfate (STS), silver nanoparticles, and $AgNO_3$, have been investigated (Geshnizjany et al. 2014; Rahman et al. 2019). However, the use of these chemicals poses risks to human health and contributes to environmental pollution (Serrano et al. 2001; McGillicuddy et al. 2017; Wang et al. 2017). Nonetheless, there is a paucity of research concerning biopreservation effects on gerbera-cut flowers. Biopreservatives, however, are derived directly from biological metabolites or their components and possess characteristics such as tastelessness, non-toxicity, and biodegradability, eliminating the risk of secondary pollution.

S. exfoliatus FT05W is a *Streptomyces* sp. isolated from plant roots. Previous studies have shown that *S. exfoliatus* FT05W is an effective biological control agent against *S. sclerotiorum* in lettuce (Chen et al. 2016). Under greenhouse conditions, it can improve the stress tolerance of horticultural plants, such as lettuce and tomato, promote their growth, and promote the germination of tobacco and vegetable seeds (Chaurasia et al. 2018). Furthermore, the secondary metabolites and bacteriostatic substances produced by *S. exfoliatus* FT05W, including chitinase, are highly effective in controlling fungal diseases and promoting plant growth (Chen et al. 2019).

Therefore, we hypothesised that inoculation with *S. exfoliatus* FT05W at different concentrations would improve the growth and durability of gerberas, although different concentrations might have different effects. The main objectives of this study were (*i*) to evaluate the effects of different concentrations of spore suspensions on the growth and vase life of gerbera cut flowers, (*ii*) the effect of bacterial spore suspension on the antioxidant system, lipid

https://doi.org/10.17221/130/2023-HORTSCI

peroxidation, and electrolyte leakage, (*iii*) to determine the effect of bacterial spore suspension on bacterial population.

MATERIAL AND METHODS

Test materials. The plant material was *G. jamesonii* Bolus, which is red in colour. *S. exfoliatus* FT05W was originally received from Prof. Marco Saracchi and Prof. Paola Sardi (Plant Pathology Lab, Department of Food, Environmental and Nutritional Sciences, University of Milan, directed by Prof. Paolo Cortesi). Previous studies have shown it can prevent and control *Sclerotinia sclerotiorum* (Chen et al. 2016). It exhibits strong inhibitory effects on various pathogenic fungi. In addition, the strain produces beneficial secondary metabolites and bacteriostatic substances, making it an effective agent against fungal diseases and a potent bacterium that promotes plant growth (Chen et al. 2019).

Culture method of *Streptomyces* sp. *Streptomyces* culture was performed using Czapek-Dox Medium, consisting of 0.1% K_2HPO_4 (w/v), 0.05% KCl (w/v), 0.3% $NaNO_3$ (w/v), 0.05% $MgSO_4$ (w/v), 0.001% $FeSO_4$ (w/v), 1.5% agar (w/v), and 3% sucrose (w/v). Sterilisation was performed at 121 °C for 20 minutes. After sterilisation, the mixture was cooled on a clean workbench. When it had cooled sufficiently, the medium was poured into a sterilised 90 mm culture dish, ensuring that aseptic procedures were strictly followed: 15 mL was poured into each culture dish, and the medium was gently shaken until it was evenly distributed at the bottom of the culture dish. Allow it to cool before use. Once the medium was completely cooled, *Streptomyces* from the mother plate of the strain was inoculated onto the medium in a wavy pattern using a streaking technique. Finally, after completing the inoculation, the plates were labelled with the date and strain number, sealed with sealing film, and placed in a constant-temperature incubator (HFP-80, Qingdao Haier Biomedical Co., Ltd., China) set between 24 °C and 28 °C for 7 days.

Preparation of *Streptomyces* spore suspension. The cultured *Streptomyces* were removed from the incubator, and the spores were gently detached from the surface of each plate with sterile water on an ultra-clean table. They were then filtered into a sterilised conical bottle using a sterilised funnel and four layers of gauze (pore size 20 μm) for use. After the preparation of the mother liquor, 1 mL of the mother liquor was absorbed and diluted using the equal dilution method. Next, 0.1 mL of spore suspension was added to the *Streptomyces* culture medium. The suspension was equally distributed by smearing with an inoculation ring and subsequently sealed. Incubate at 24–28 °C in a constant temperature and light incubator for a week, and the number of colonies was counted to calculate the mother liquor concentration. After determining the concentration, the mother liquor was diluted with sterile water according to treatment requirements and transferred to a sterilised centrifuge tube for later use.

Treatment of *G. jamesonii* L. fresh-keeping test. We used sucrose (20 g/L sucrose) and calcium nitrate (10 g/L sodium nitrate) as the basic preservation solution components. We then tested different concentrations of *S. exfoliatus* FT05W spore suspensions. The arrangement of bottles was determined according to the treatment plan outlined in Table 1.

The experiment was conducted at the Horticultural Laboratory of Guizhou University. We selected fresh flowers and branches that had bloomed for the first time, showed even growth, and were free of diseases or pests. After collecting flower samples, they were placed in clean water. Each stem was cut diagonally at an angle of 45 degrees underwater, ensuring that each stem cut was approximately 30 cm from the diagonal cut to the flower tip. They were then placed in triangular bottles containing 300 mL of the treatment solution, with three stems per bottle. This process was repeated thrice for each treatment. To minimise evaporation, each bottle was sealed with absorbent cotton. These bottles were stored

Table 1. Treatment of *G. jamesonii* L. fresh-keeping test

Treatment	Treatment detail
CK (control)	basic preservation solution + sterile water
A	basic preservation solution + 1.0×10^4 CFU/mL FT05W
B	basic preservation solution + 1.0×10^5 CFU/mL FT05W
C	basic preservation solution + 1.0×10^6 CFU/mL FT05W
D	basic preservation solution + 1.0×10^7 CFU/mL FT05W
E	basic preservation solution + 1.0×10^8 CFU/mL FT05W

https://doi.org/10.17221/130/2023-HORTSCI

in a controlled environment with a consistent temperature of approximately 25 °C and a relative humidity between 60% and 80%. The chosen location ensured no direct sunlight but allowed adequate ventilation and clarity. At the later stage of the experiment (14 days), we calculated the number of single colonies in the preservative solution. We also assessed the longevity of cut flowers by recording their appearance and other morphological parameters at 8 a.m. each day. In addition, various physiological measures were conducted at 48-hour intervals until the flowers lost their decorative appeal.

Appearance quality and vase life. Changes in the appearance of cut flowers were recorded daily and included phenomena such as petal wilting and stem bending. The first vase day was recorded as day 0. The end of vase life was determined when more than 50% of the tongue petals had lost water, resulting in wilting, bending, or drooping of the flower stalks or heads.

Maximum increase rate of blossom diameter (IR_D). The blossom diameter of the *G. jamesonii* was recorded daily with a calliper, and the average value was determined. IR_D (%) was calculated using the following formula:

$$IR_D\ (\%) = (D_f - D_i)/D_i \times 100 \quad (1)$$

where: D_f – final maximum diameter; D_i – initial maximum diameter.

The change rate of fresh weight (FWCR). The fresh weight (FW) of each flower is measured daily using an electronic scale, and the initial FW is the average FW of the flowers on the first day (day 0). The change in FW is then calculated using the following formula:

$$FWCR\ (\%) = (FW_t - FW_i)/FW_i \times 100 \quad (2)$$

where: FW_t – FW of cut flowers on the measurement day; FW_i – initial FW of cut flowers.

Water balance (WB) value. WB value is measured using the weighing method (Kong et al. 2021). The following formula is used to measure the WB value:

$$WB = WA - WL \quad (3)$$

where: WA – water absorption; WL – water loss.

The anthrone-ethyl acetate method was used to measure the soluble sugar (SS) content (Jhanji et al. 2022). The soluble protein (SP) content was measured using the Coomassie brilliant blue G-250 method proposed by Jhanji et al. (2022).

Determination of plant enzymatic activities. Fresh leaves (weighing 0.5 g) were collected and crushed with 2 mL of potassium phosphate buffer with a pH of 7.8. Afterwards, this supernatant was centrifuged (Hunan Xiangyi Laboratory Instrument Development Co., Ltd., China) at 4 °C for 20 min at 1 000.0 × g. The supernatant was further analysed for enzymatic activities. Superoxide dismutase (SOD) activity was quantified by the reduction of nitro blue tetrazolium (NBT). The detailed procedure has been reported previously by Sun et al. (2019). The guaiacol method proposed by Bestwick et al. (1998) was used to assess the peroxidase (POD) activity, and absorbance was recorded at a wavelength of 470 nm. To estimate catalase (CAT) activity in gerbera leaves, we have employed the procedure proposed by Chance and Maehly (1955).

Relative electrolyte leakage (REL). REL was estimated using the procedure developed by Dhindsa and Matowe (1981), and the results were quantified as follows:

$$REL\ (\%) = (EC_1 - EC_0)/(EC_2 - EC_0) \times 100 \quad (4)$$

where: EC_1 – electrical conductivity value of the sample after specific treatment; EC_0 – electrical conductivity value of the blank control; EC_2 – electrical conductivity value of the sample after high-temperature boiling.

Malondialdehyde (MDA) content. MDA content was assessed using the thiobarbituric acid reaction procedure (Tiwari et al. 2010).

Colony culture and colony number determination. The preservation solutions were diluted in equal proportions, and 0.2 mL of the resulting mixture was uniformly spread on beef paste peptone medium. Each concentration was replicated 3–5 times. The culture plates were sealed and incubated at a constant temperature of 37 °C for 18–24 hours. The growth of the colonies was observed periodically, and the number of colonies was recorded. The concentration of the mother liquor (CFU/mL) was calculated using the formula:

$$CFU/mL = C_{mean} \times \text{dilution factor } 5 \quad (5)$$

where: C_{mean} – mean number of colonies.

https://doi.org/10.17221/130/2023-HORTSCI

Statistical Analysis. Data were subjected to analysis of variance (ANOVA) using SPSS version 22.0 software. Data recorded as percentages were transformed by arcsine square root prior to analysis using ANOVA. Data are presented as the mean of three technical replicates ± SE (standard error). Means with the same letter do not significantly differ at $P < 0.05$ (Tukey's HSD test).

RESULTS

Effect of *S. exfoliatus* FT05W on vase life and the increase rate of maximum blossom diameter on *G. jamesonii* L. cut-flowers. Different concentrations of preservation solution in combination with *S. exfoliatus* FT05W have different effects on the vase life and blossom diameter of *G. jamesonii* (Table 2). Treatment C significantly prolonged the vase life of *G. jamesonii*, reaching 18.67 days, which was 4 days longer than the control (CK). In addition, the vase life was significantly increased under D, B, E, and A treatments by 3.00, 2.66, 1.69, and 1.66 days longer in comparison with the control (CK), respectively. Concurrently, treatments with *S. exfoliatus* FT05W significantly augmented the maximum floral diameter rate, except for treatment A, compared to the control (CK). The most significant enhancement (177.95%) was observed in treatment C. This was followed by treatments D, B, E, and A, which increased by 122.31, 92.82, 61.02, and 34.36%, respectively. Overall, treatment C showed the highest rate of increase in the maximum flower diameter.

Table 2. Effects of *S. exfoliatus* FT05W on vase life and maximum diameter of *G. jamesonii.* L. fresh-cut flowers

Treatment	Vase life (days)	Bottle life extension (days)	Increase rate of maximum flower diameter (%)
CK (control)	14.67^{d}	0.00	3.90^{c}
A	16.33^{c}	1.66	5.24^{c}
B	17.33^{b}	2.66	7.52^{b}
C	18.67^{a}	4.00	10.84^{a}
D	17.67^{b}	3.00	8.67^{b}
E	16.31^{c}	1.69	6.28^{c}

For treatment detail (CK–E) see Table 1

$^{a–d}$values with different lowercase letters indicate significant differences ($P < 0.05$)

Effect of *S. exfoliatus* FT05W on the appearance quality of *G. jamesonii* L. cut-flowers. On the 7th day post-bottle insertion, neither the treated flowers (A–E) nor the control cut flowers (CK) showed any signs of wilted petals, drooping flower heads, or bent stems (Figure 1). On the 8th day, the petals of the CK branches exhibited signs of dehydration and wilting, leading to noticeable changes in the appearance and quality of the cut flowers. By the 10th day after being placed in the bottle, pronounced wilting of the flowers and bending of their stems was evident in all treatments, including control (CK). The changes in treatments C and D were minor, resulting in only minor water loss. By day 14, two-thirds of the tongue-shaped petals of the cut flowers in the CK group had undergone desiccation and subsequent wilting, which significantly reduced their aesthetic appeal. In contrast, the branches subjected to treatment C remained healthy, with only slight dehydration of the petals and preservation of their vibrant colour. Compared to all treatments, treatment C was the least affected by flower wilting, followed by treatment D. Treatments A, B, and E showed more pronounced wilting, whereas the CK group was the most affected. This indicates that *S. exfoliatus* FT05W supports gerbera stalks, prevents flower heads from sagging, keeps cut flower stems straight, and significantly increases the shelf life and ornamental quality of cut flowers. The addition of a preservation solution containing 1.0×10^6 CFU/mL *S. exfoliatus* FT05W gave the most favourable result, as shown in Figure 1.

Effect of *S. exfoliatus* FT05W on fresh weight change rate of *G. jamesonii* L. cut-flowers. As shown in Figure 2, there was an initial increase in the rate of FW change across all the experimental groups, followed by a subsequent decrease. The rate of FW change for treatments CK, A, B, D, and E peaked 3 days after bottle insertion, before showing a subsequent decline. In contrast, the rate of treatment C increased significantly compared to that of CK, continuing to rise until the 5th day before declining. At day 12, the rates of FW change in treatments CK through E decreased by 32.18%, 16.97%, 13.30%, 12.18%, 16.01%, and 16.96%, respectively, compared to day 0. When ranked by rate of change, the treatments followed the order CK > A > E > D > B > C. Treatments C and B exhibited the lowest rates of change, followed by treatments D and E. Treatment A displayed a marginally higher rate of change, whereas the highest rate was observed in the CK treatment.

https://doi.org/10.17221/130/2023-HORTSCI

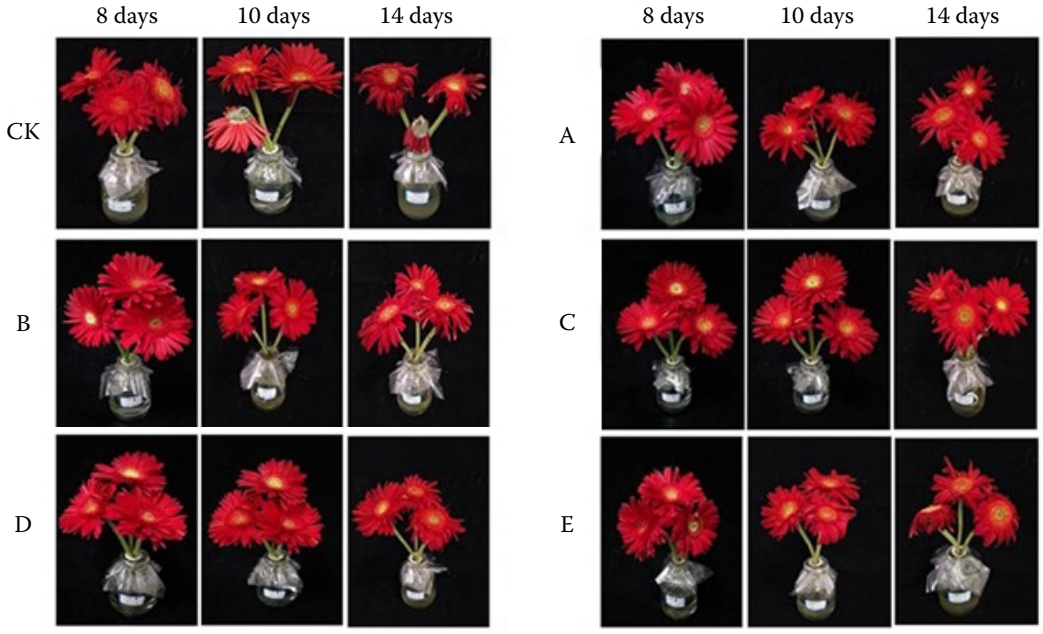

Figure 1. Effects of *S. exfoliatus* FT05W on the appearance quality of *G. jamesonii* L. fresh-cut flowers
For treatment detail (CK–E) see Table 1

During the testing process, it was observed that each *S. exfoliatus* FT05W treatment group performed better than the control group in each phase. After conducting further tests to determine the optimal concentration of *S. exfoliatus* FT05W, we found that gerbera treated with a concentration of 1.0×10^6 CFU/mL FT05W had a higher FW compared to the other treatments. Therefore, we confirmed that a concentration of 1.0×10^6 CFU/mL of *S. exfoliatus* FT05W is most effective for extending the vase life of *G. jamesonii*. This concentration maximised water absorption during the initial stage of bottle insertion and minimised water loss in the later stages, thereby indicating its superior preservative effect.

Effect of *S. exfoliatus* FT05W on the water balance value of *G. jamesonii* L. cut-flowers. Figure 3 shows that the water balance values for each treatment exhibited a consistent downward trend throughout the experiment. On day 12 after bottle insertion, the sum of the water balance values for CK and treatments A, B, C, D, and E were –26.92, –9.61, –8.18, –0.13, –8.58 and –14.70, respectively. The treatments can be ranked based

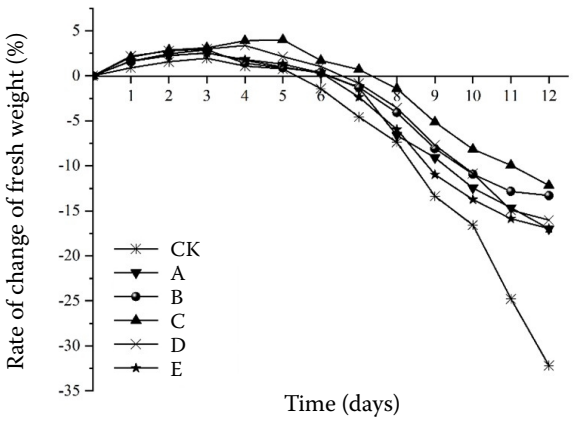

Figure 2. Effects of *S. exfoliatus* FT05W on the fresh weight of cut *G. jamesonii* L. fresh-cut flowers
For treatment detail (CK–E) see Table 1

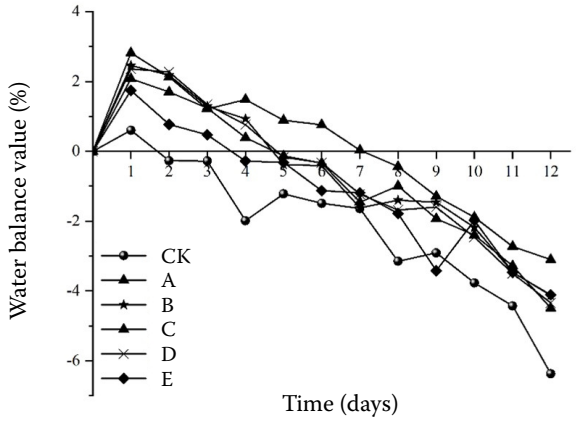

Figure 3. Effect of *S. exfoliatus* FT05W on the water balance value of *G. jamesonii* L. flowers
For treatment detail (CK–E) see Table 1

https://doi.org/10.17221/130/2023-HORTSCI

on their water balance values in the following order: C > B > D > A > E > CK. Regarding the time needed to disturb the water balance, CK was negative on day 2 after bottle insertion; treatment E shifted to negative on day 4; treatments A, B, and D only on day 5; and treatment C remained stable through day 8. These results indicate that *S. exfoliatus* FT05W is effective in maintaining the water balance of *G. jamesonii* L. cut flowers, thereby contributing to improved stem vigour.

Effect of *S. exfoliatus* FT05W on SS and SP content of *G. jamesonii* L. fresh-cut flowers. Different concentrations of *S. exfoliatus* FT05W enhanced SP and SS levels (Figure 4), compared to the control (CK). Overall, the pattern of increase in these parameters was consistent, that is, the maximum increase in both SP and SS content was observed under 1 × 10^6 CFU/mL *S. exfoliatus* FT05W, and SS content was significantly higher under C, D, and B treatments by 43.91%, 33.33%, and 28.19%, respectively, compared to the control (CK). A similar pattern was observed for the SP content. Treatment C significantly enhanced the SP content, which was 49.56% higher than the control, followed by treatments D, B, and A.

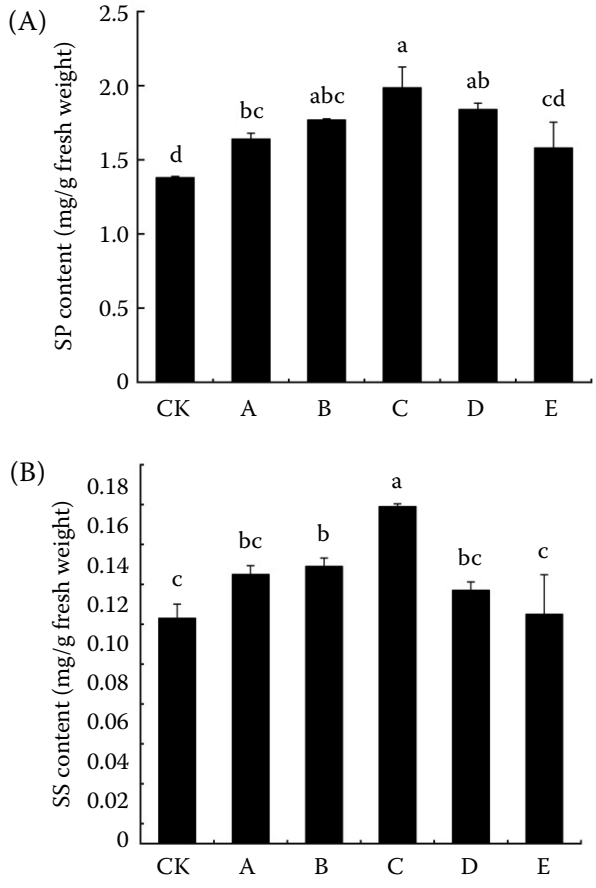

Figure 4. Effects of *S. exfoliatus* FT05W treatment on (A) soluble protein (SP) and (B) soluble sugar (SS) contents of *G. jamesonii* L. fresh-cut flowers

For treatment detail (CK–E) see Table 1

[a–d]different lowercase letters indicate significant differences ($P < 0.05$)

Effect of *S. exfoliatus* FT05W on SOD, POD, and CAT activities of *G. jamesonii* L. fresh-cut flowers. Relative to the control, the application of different concentrations of *S. exfoliatus* FT05W enhanced the activities of the antioxidant enzymes SOD, POD, and CAT in all treatments (Figure 5A–C). SOD activity was higher in the D, C, and B treatments by 52.22%, 43.89%, and 40.00%, respectively, compared with the control (CK) (Figure 5A).

Similarly, POD activity significantly increased under different concentrations of *S. exfoliatus* FT05W (Figure 5B). However, the highest increase in POD was observed under treatment C (1 × 10^6 CFU/mL), which was 83.13% higher than the control (CK), followed by treatment B (44.94%) and D (25.77%). Similarly, CAT activity was also enhanced by *S. exfoliatus* FT05W treatment. Compared with the control, its activity was enhanced by 67.72% in treatment C. It increased by 58.53%, 49.68%, and 46.30% in D, A, and B, respectively (Figure 5C).

Impact of *S. exfoliatus* FT05W on microbial colonisation in vase solutions for *G. jamesonii* L. fresh-cut flowers. The data presented in Figure 5D showed that all *Streptomyces* treatments effectively inhibited microbial growth. Among them, treatment C showed the lowest number of microbes in the vase liquid with a count of 1.7 × 10^6 CFU/mL, which is 87.02% lower than that of CK. Following this were treatments A, B, D, and E with microbial counts of 6.6 × 10^6 CFU/mL, 4.1 × 10^6 CFU/mL, 5.4 × 10^6 CFU/mL and 7.6 × 10^6 CFU/mL. This corresponds to reductions of 49.62%, 68.70%, 58.78%, and 41.98%, respectively, compared to the control (CK). The control (CK) had the highest bacterial count in the vase liquid, reaching 13.1 × 10^6 CFU/mL. This indicates that the addition of a spore suspension of *S. exfoliatus* FT05W to the vase liquid can effectively inhibit microbial growth. The most pronounced antimicrobial effect was observed at 1.0 × 10^6 CFU/mL.

***S. exfoliatus* FT05W reduced oxidative damage in the content of *G. jamesonii* L. fresh-cut flowers.** The basic preservation solution + sterile water exhibited an increase in lipid peroxidation and REL (Figure 6). In contrast, *S. exfoliatus* FT05W amelio-

https://doi.org/10.17221/130/2023-HORTSCI

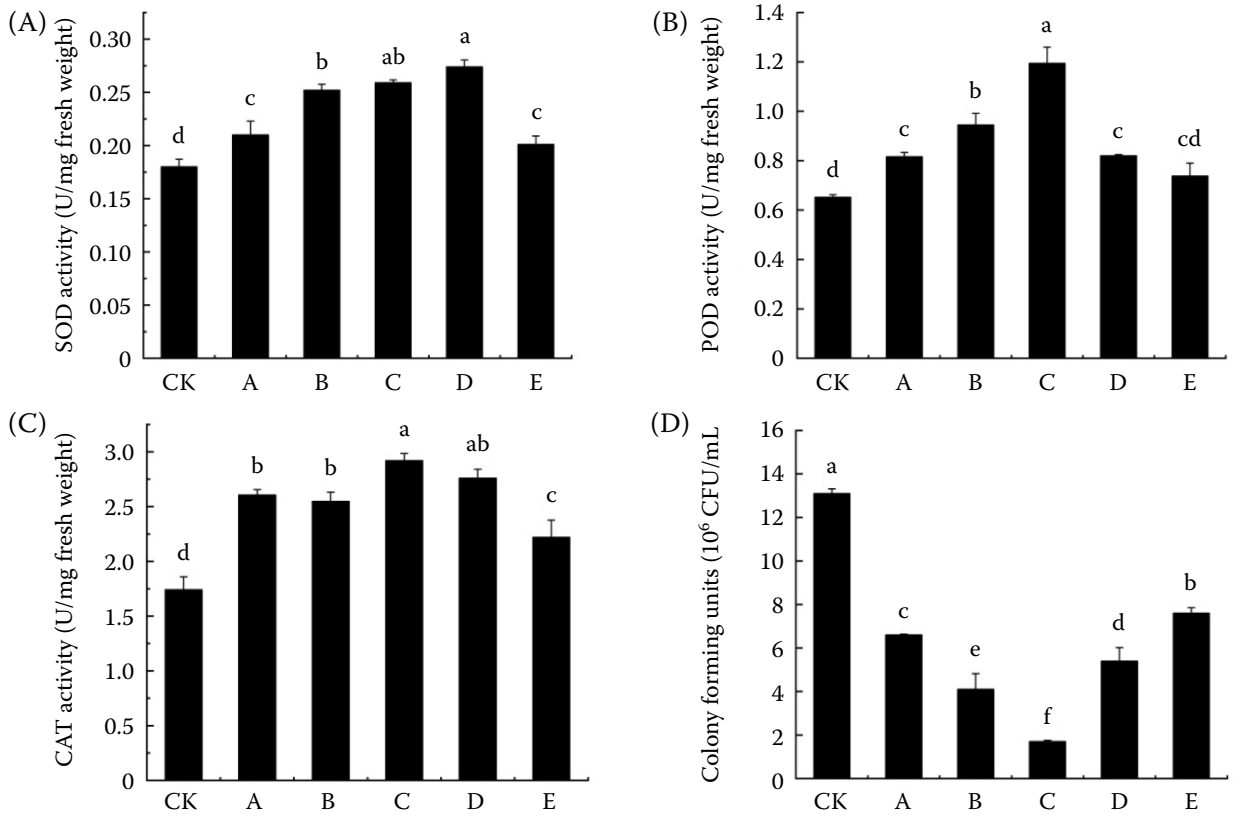

Figure 5. Effects of *S. exfoliatus* FT05W on activities of (A) superoxide dismutase (SOD), (B) peroxidase (POD), (C) catalase (CAT) and (D) the number of colonies in bottle insertion (CFU) of *G. jamesonii* L. fresh-cut flowers

For treatment detail (CK–E) see Table 1

[a–f]different lowercase letters indicate significant differences ($P < 0.05$)

rated oxidative stress by reducing MDA and REL accumulation. The highest reduction in MDA and REL was observed under treatment C, suggesting that control plants underwent a robust peroxidation process, which led to increased cell membrane damage and significant petal ageing. Treatment with *S. exfoliatus* FT05W mitigated the increase in MDA and REL content in the cut flowers, effectively delaying the ageing process of *G. jamesonii* L. fresh-cut flowers, with treatment C being the most effective.

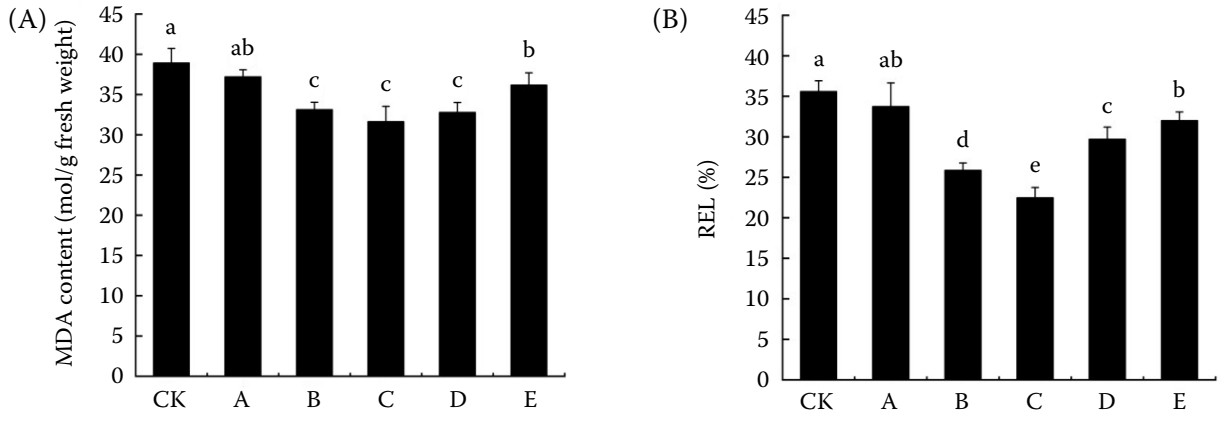

Figure 6. Effect of *S. exfoliatus* FT05W on (A) malondialdehyde (MDA) and (B) relative electrolyte leakage (REL) of *G. jamesonii* L. fresh-cut flowers

For treatment detail (CK–E) see Table 1

[a–e]different lowercase letters indicate significant differences ($P < 0.05$)

https://doi.org/10.17221/130/2023-HORTSCI

DISCUSSION

In the existing literature, a connection has been found between the wilting of the petals of cut flowers and the presence of bacteria either on the surface of the cut stems or in the vase solution (Li et al. 2012; Hongbo et al. 2017). Nevertheless, several studies have reported mixed results regarding the effects of introducing an external bacterial suspension at a concentration of less than 10^8 CFU/mL on the lifespan of cut flowers (van Doorn et al. 1991; van Doorn et al. 1995). Some studies found that this solution had no significant effect or slightly reduced the flower vase life (van Doorn et al. 1991; van Doorn et al. 1995). Conversely, Ratnayake et al. (2012) and Williamson and Joyce (2013) reported that high bacterial concentrations had no visible effect on the vase life of *Boronia heterophylla* and *Acacia holosericea* cut flowers. These differences in results could be due to the different types of bacteria used in the respective experiments. Detailed studies on bacterial growth have shown that bacterial shortening of vase life depends on the specific type of bacteria present in the vase solution (Jacob, Kim 2010; Carlson et al. 2015). However, in the present study, *G. jasmonii* treated with the vase solution of *S. exfoliatus* FT05W significantly increased flower quality parameters such as vase life days, bottle insertion days, blossom diameter, and rate of change of FW compared with the control, and the highest increase in these parameters was observed under treatment C (*S. exfoliatus* FT05W 1.0×10^6 CFU/mL). The prolonged vase life of *G. jasmonii* is attributed to a positive impact on maintaining optimal water balance, which is evident in flower diameter, bottle insertion days, water balance, and rate of change in FW. Furthermore, maintaining water homeostasis throughout the flower growth period has been important in extending the vase life of flowers. In contrast, imbalances in water regulation have been seen to accelerate the senescence process (Hassan, Ali 2014). Biocontrol bacteria often exhibit their beneficial effects by inhibiting the growth and propagation of phytopathogens through several mechanisms. These mechanisms include producing toxic compounds that harm phytopathogens, the competitive acquisition of vital nutrients and colonisation sites, and the induction of defence response-related genes (Gao et al. 2012; Carlson et al. 2015). Similarly, *Streptomyces* sp. is a genus of bacteria known for its diverse metabolic capabilities, including the production of various bioactive compounds. Many strains of *Streptomyces* sp. have been found to possess antimicrobial properties and are capable of producing secondary metabolites that inhibit the growth of microorganisms, and exhibit oxidase-negative and catalase-positive properties (Alam et al. 2022). *Streptomyces* sp. may have the potential to eliminate microorganisms present in the vase solution that could accelerate the deterioration of flowers. By inhibiting the growth of these microorganisms, the vase solution remains cleaner and more suitable for maintaining the freshness and longevity of the flowers (Jowkar et al. 2017; Abdel-Rahman 2019). Similar results were obtained in our study, and the vase solution of treatment C significantly reduced the number of bacteria compared to control (CK).

Furthermore, an alternative explanation could be that the absence of oxidase activity contributes to reducing reactive oxygen species (ROS) production induced by oxidases. Furthermore, the catalase-positive property of this substance enhances its antioxidant activity, facilitating the efficient removal of ROS that could potentially damage plant cell membranes (Naing et al. 2017). Our results are in line with the previous study conducted by Carlson et al. (2015), which observed that two bacterial strains, *Pseudomonas fulva* and *Escherichia coli*, commonly referred to as biocontrol bacteria, prolong the vase life of cut *Zinnia elegans* flowers. Similarly, the blossom diameter increased due to the vase solution of *S. exfoliatus* FT05W. The significant factor contributing to the decrease in water uptake, which leads to xylem blockage and reduces the water balance, is the continued growth of microorganisms in the chemical preservation solution, as previously described by Nguyen and Lim (2021). In addition, the proliferation of bacteria in vase solutions leads to blockage of the vascular system. The presence of occlusion hinders the process of water balance absorption, ultimately resulting in shortened flower vase life, smaller blossom diameter, and a lower rate of change in FW (Hongbo et al. 2017; Akhtar et al. 2021). Conversely, the vase solution of *S. exfoliatus* FT05W, with its antimicrobial characteristics, led to an increase in the diameter of the gerbera blossom. The antimicrobial properties exhibited by *Streptomyces* have been observed to effectively inhibit bacterial growth, thereby promoting water absorption and increasing blossom diameter. This effect is clearly demonstrated in Table 5A. Fur-

https://doi.org/10.17221/130/2023-HORTSCI

thermore, basic fresh-keeping solution and sterile water (CK) treatment enhanced ROS production, which is directly related to the overproduction of lipid peroxidation and electrolyte leakage (Ghani et al., 2022a; Qi et al. 2023).

The primary method of preserving cut flowers is to provide the necessary nutrients via a fresh-keeping solution to preserve freshness, maintain water balance, and inhibit the physiological changes of cut flower ageing, as well as extend the life of fresh-cut flowers and improve their ornamental quality (Put 1990; Elhindi 2012; Perik et al. 2012). A major factor that contributes to the ageing process of fresh-cut flowers is the proliferation of bacteria in the fresh-keeping liquid. This bacterial growth results in the closure of the flower's vascular system, subsequently inducing water stress (van Meeteren, van Gelder 1999).

When plants are exposed to various biological and abiotic stresses, they generate a significant amount of ROS in their cells. These ROS can disrupt the dynamic balance of the cell, hinder the normal physiological processes of plants, and lead to cell death. The increase in REL and MDA in cells is one of the first symptoms of destabilising these structures. Various stress conditions produce ROS and lead to the peroxidation of membrane lipids. Under such conditions, the amounts of MDA as an end product of oxidation increase, indicating membrane permeability and disruption. To counteract excessive ROS production, the plant activates the antioxidant system, which protects cells from oxidative stress caused by pathogens and water deficiency. This protection helps prevent senescence and cell death (Zhou et al. 2021; Ghani et al. 2022b; Ghani et al. 2023).

In the present study, the application of *Streptomyces* FT05W vase solution inhibited the MDA level, known as the end product of lipid peroxidation (Miller et al. 2010) and REL level. The results indicated that 1.0×10^6 CFU/mL FT05W vase solution exhibited significantly lower levels of MDA compared to CK (basic fresh-keeping solution + sterile water); this may be due to its antimicrobial properties and the activation of the antioxidant system, as supported by the higher activities of antioxidant enzymes such as CAT, POD, and SOD in gerbera cut flower. The augmentation of the antioxidant capacity of the cut flowers resulted in a reduction of ROS and the consequent damage to membrane lipids. This subsequently led to a drop in REL and MDA levels in cut flowers. Similarly, Naveed et al. (2022) also observed decreased MDA levels and REL in meri gold cut flowers following the treatment of endophytic bacteria.

It is noted that microbial invasion in the fresh-keeping solution is one of the main factors determining the vase life and the quality of the ornamental plant. It is an important method for extending vase life by inhibiting the proliferation and growth of microorganisms at the base of the flower stalk and reducing the blockage of metabolites at the flower stalk vessel (Gururani et al. 2023). In this study, it was found that the number of colonies in the bottled solution of all *S. exfoliatus* FT05W-treated groups was significantly lower than that of the control group, and the number of colonies in the bottled solution of treatment C was lowest, which was reduced by 87.02% compared to the control group. The results suggest that *S. exfoliatus* FT05W establishes dominance through effective competition for nutrients and growth space, thereby displaying antagonistic effects. Consequently, *S. exfoliatus* FT05W showcases a pronounced antibacterial effect, effectively suppressing microbial propagation and thereby prolonging the vase life of gerbera cut flowers. Regrettably, we did not specifically differentiate or quantify the beneficial and harmful microorganisms present in the preservative solution after adding *S. exfoliatus* FT05W. In future work, we plan to employ techniques such as microbial diversity analysis, metagenomic sequencing, and fluorescent molecular markers to address this issue, providing insights into the mechanisms related to the microbial interaction following FT05W addition.

CONCLUSION

The findings of a recent study highlight that adding bacteria *S. exfoliatus* FT05W to the vase solution, particularly 1.0×10^6 CFU/mL FT05W, has a positive impact on *G. jasmonii* and keeps the quality and extends the longevity of *G. jasmonii.* The addition of spore suspension of bacteria *S. exfoliatus* FT05W, particularly the vase solution with a concentration of 1.0×10^6 CFU/mL stem end cut surface. Furthermore, the positive impact was observed through augmentation of the antioxidant system, which reduced lipid peroxidation, REL, which reduced bacteria blockage of xylem, hence maintaining water balance in the plant and increased maximum flower diameter and thus prolonged gerbera vase life. A concentration of 1.0×10^6 CFU/mL of *S. exfoliatus*

https://doi.org/10.17221/130/2023-HORTSCI

FT05W significantly reduced the number of bacteria in the vase solution, with an underlying potential of integrating *S. exfoliatus* FT05W to promote sustainable and healthier flower cultivation while minimising environmental problems. However, additional research is needed to investigate the deeper mechanisms, including physiological and biochemical reactions and molecular biological mechanisms. These further studies will help provide a solid theoretical basis for the application of *S. exfoliatus* FT05W in the floriculture field to increase the vase life of other cut flowers.

Acknowledgement: The authors greatly acknowledge Prof. Marco Saracchi, Prof. Paola Sardi and the Plant Pathology Lab, directed by Prof. Paolo Cortesi, Department of Food, Environmental and Nutritional Sciences, University of Milan, for their kindness in gifting related strains in history. The authors are grateful to Miss Xin Li, Miss Ying Qi and Mr. Qiang Peng for their valuable assistance in laboratory work.

REFERENCES

Abdel-Rahman T. (2019): Evaluation activity of some antimicrobial agents in reduction microbial load and their impact on vase life of *Asparagus aethiopicus* L. Egyptian Journal of Phytopathology, 47: 157–178.

Acharyya P., Mukherjee D., Chakraborty S., Chakraborty L. (2013): Effects of flower preservatives on the vase life of gerbera (*Gerbera jamesonii* H. Bolus) flowers. Acta Horticulturae (ISHS), 970: 287–292.

Akhtar G., Rajwana I.A., Sajjad Y., Shehzad M.A., Amin M., Razzaq K., Ullah S., Faried H.N., Farooq A., Samiullah K. (2021): Do natural leaf extracts involve regulation at physiological and biochemical levels to extend vase life of gladiolus cut flowers? Scientia Horticulturae, 282: 110042.

Alam K., Mazumder A., Sikdar S., Zhao Y., Hao J., Song C., Wang Y., Sarkar R., Islam S., Zhang Y., Li A. (2022): *Streptomyces*: The biofactory of secondary metabolites. Frontiers in Microbiology, 13: 968053.

Balestra G., Agostini R., Mencarelli F., Bellincontro A., Varvaro L. (2005): Bacterial populations related to gerbera (*Gerbera jamesonii* L.) stem break. Phytopathologia Mediterranea, 44: 291–299.

Bestwick C.S., Brown I.R., Mansfield J.W. (1998): Localized changes in peroxidase activity accompany hydrogen peroxide generation during the development of a non-host hypersensitive reaction in lettuce. Plant Physiology, 118: 1067–1078.

Carlson A.S., Dole J.M., Matthysse A.G., Hoffmann W.A., Kornegay J.L. (2015): Bacteria species and solution pH effect postharvest quality of cut *Zinnia elegans*. Scientia Horticulturae, 194: 71–78.

Chance B., Maehly A.C. (1955): [136] Assay of catalases and peroxidases. Methods in Enzymology, 2: 764–775.

Chaurasia A., Meena B.R., Tripathi A.N., Pandey K.K., Rai A.B., Singh B. (2018): *Actinomycetes*: An unexplored microorganisms for plant growth promotion and biocontrol in vegetable crops. World Journal of Microbiology and Biotechnology, 34: 132.

Chen X., Pizzatti C., Bonaldi M., Saracchi M., Erlacher A., Kunova A., Berg G., Cortesi P. (2016): Biological control of lettuce drop and host plant colonization by rhizospheric and endophytic *Streptomycetes*. Frontiers in Microbiology, 7: 714.

Chen X., Qin K., Sang W., Saracchi M., Cortesi P. (2019): Draft genome sequencing of *Streptomyces exfoliatus* FT05W, a biological control strain against plant soil-borne pathogens. Journal of Biotechnology, 305: S70.

Danaee E., Mostofi Y., Moradi P. (2011): Effect of GA_3 and BA on postharvest quality and vase life of gerbera (*Gerbera jamesonii*. cv. Good timing) cut flowers. Horticulture, Environment, and Biotechnology, 52: 140–144.

Dhindsa R.S., Matowe W. (1981): Drought tolerance in two mosses: Correlated with enzymatic defence against lipid peroxidation. Journal of Experimental Botany, 32: 79–91.

Elhindi K.M. (2012): Effects of postharvest pretreatments and preservative solutions on vase life longevity and flower quality of sweet pea (*Lathyrus odoratus* L.). Photosynthetica, 50: 371–379.

Gantait S., Mandal N., Bhattacharyya S., Das P.K. (2011): Induction and identification of tetraploids using *in vitro* colchicine treatment of *Gerbera jamesonii* Bolus cv. Sciella. Plant Cell, Tissue and Organ Culture (PCTOC), 106: 485–493.

Gao X., Lu X., Wu M., Zhang H., Pan R., Tian J., Li S., Liao H. (2012): Co-inoculation with rhizobia and AMF inhibited soybean red crown rot: From field study to plant defense-related gene expression analysis. Plos One, 7: e33977.

Geshnizjany N., Ramezanian A., Khosh-Khui M. (2014): Postharvest life of cut gerbera (*Gerbera jamesonii*) as affected by nano-silver particles and calcium chloride. International Journal of Horticultural Science and Technology, 1: 171–180.

Ghani M.I., Ali A., Atif M.J., Ali M., Ahanger M., Chen X., Cheng Z. (2023): Different leafy vegetable cropping systems regulate growth, photosynthesis, and PSII functioning in mono-cropped eggplant by altering chemical properties and upregulating the antioxidant system. Frontiers in Plant Science, 14: 1132861.

https://doi.org/10.17221/130/2023-HORTSCI

Ghani M.I., Ali A., Atif M.J., Ali M., Amin B., Cheng Z. (2022a): Arbuscular mycorrhizal fungi and dry raw garlic stalk amendment alleviate continuous monocropping growth and photosynthetic declines in eggplant by bolstering its antioxidant system and accumulation of osmolytes and secondary metabolites. Frontiers in Plant Science, 13: 849521.

Ghani M.I., Saleem S., Rather S.A., Rehmani M.S., Alamri S., Rajput V.D., Kalaji H.M., Saleem N., Sial T.A., Liu M. (2022b): Foliar application of zinc oxide nanoparticles: An effective strategy to mitigate drought stress in cucumber seedling by modulating antioxidant defense system and osmolytes accumulation. Chemosphere, 289: 133202.

Gururani M.A., Atteya A.K., Elhakem A., El-Sheshtawy A.A., El-Serafy R.S. (2023): Essential oils prolonged the cut carnation longevity by limiting the xylem blockage and enhancing the physiological and biochemical levels. PloS One, 18: e281717.

Hassan F., Ali E. (2014): Longevity and postharvest quality of *Rosa hybrida* L. cv. 'Happy Hour' cut flowers as affected by Silver thiosulphate (STS) treatment. Scientia Agriculturae, 5: 85–91.

Hongbo L., Liu J., Luo Z., Joyce D., He S. (2017): Nano-silver treatments reduced bacterial colonization and biofilm formation at the stem-ends of cut gladiolus 'Eerde' spikes. Postharvest Biology and Technology, 123: 102–111.

Jacob B.M., Kim E. (2010): Inhibiting biofilm formation of *Enterobacter* sp. prevented premature withering in cut flowers. Korean Journal of Chemical Engineering, 27: 1252–1257.

Jhanji S., Kaur G., Kaur R., Dhatt U.K. (2022): Physiological and biochemical changes during flower development and senescence in Chrysanthemum and Gladiolus. Acta Physiologiae Plantarum, 45: 14.

Jowkar M.M., Hasanzadeh N., Kafi M., Khalighi A. (2017): Comprehensive microbial study on biocide application as vase solution preservatives for cut 'Cherry Brandy' rose flower. International Journal of Horticultural Science and Technology, 4: 89–103.

Karras G., Savvas D., Patakioutas G., Pomonis P., Albanis T. (2007): Fate of cyromazine applied in nutrient solution to a gerbera (*Gerbera jamesonii*) crop grown in a closed hydroponic system. Crop Protection, 26: 721–728.

Kong L., Li F., Du R., Geng H., Li S., Wang J. (2021): Effects of different preservatives on cut flower of *Luculia pinceana*: A novel fragrant ornamental species. HortScience, 56: 795–802.

Li C., Fan Y., Luan W., Dai Y., Wang M., Wei C., Wang Y., Tao X., Mao P., Ma X. (2019): Titanium ions inhibit the bacteria in vase solutions of freshly cut *Gerbera jamesonii* and extend the flower longevity. Microbial Ecology, 77: 967–979.

Li H., Huang X., Li J., Liu J., Joyce D., He S. (2012): Efficacy of nano-silver in alleviating bacteria-related blockage in cut rose cv. Movie Star stems. Postharvest Biology and Technology, 74: 36–41.

McGillicuddy E., Murray I., Kavanagh S., Morrison L., Fogarty A., Cormican M., Dockery P., Prendergast M., Rowan N., Morris D. (2017): Silver nanoparticles in the environment: Sources, detection and ecotoxicology. Science of the Total Environment, 575: 231–246.

Mehdikhah M., Onsinejad R., Ilkaee M.N., Kaviani B. (2016): Effect of salicylic acid, citric acid and ascorbic acid on post-harvest quality and vase life of gerbera (*Gerbera jamesonii*) cut flowers. Journal of Ornamental Plants, 6: 181–191.

Miller G., Suzuki N., Ciftci-Yilmaz S., Mitter R. (2010): Reactive oxygen species homeostasis and signalling during drought and salinity stresses. Plant, Cell & Environment, 33: 453–467.

Mohammadi M., Aelaei M., Saidi M. (2020): Antibacterial properties of *Scrophularia striata* Boiss. (Tashenehdari) extract on vase life improvement in "Stanza" and "Pink Elegance" gerbera cut flowers. Biocatalysis and Agricultural Biotechnology, 28: 101738.

Naing A.H., Win N.M., Han J., Lim K.B., Kim C.K. (2017): Role of nano-silver and the bacterial strain *Enterobacter cloacae* in increasing vase life of cut carnation 'Omea'. Frontiers in Plant Science, 8: 1590.

Naing A.H., Kim C.K. (2020): Application of nano-silver particles to control the postharvest biology of cut flowers: A review. Scientia Horticulturae, 270: 109463.

Naveed M., Hafeez S., Rafique M., Mumtaz M.Z., Subhani Z., Holatko J., Hammerschmiedt T., Malicek O., Mustafa A., Kintl A., Brtnicky M. (2022): Plant-endophyte mediated improvement in physiological and bio-protective abilities of marigold (*Tagetes patula*). Frontiers in Plant Science, 13: 993130.

Nguyen T., Lim J.H. (2021): Do eco-friendly floral preservative solutions prolong vase life better than chemical solutions? Horticulturae, 7: 415.

Perik R.R.J., Razé D., Ferrante A., van Doorn W.G. (2014): Stem bending in cut *Gerbera jamesonii* flowers: Effects of a pulse treatment with sucrose and calcium ions. Postharvest Biology and Technology, 98: 7–13.

Perik R.R.J., Razé D., Harkema H., Zhong Y., van Doorn W.G. (2012): Bending in cut *Gerbera jamesonii* flowers relates to adverse water relations and lack of stem sclerenchyma development, not to expansion of the stem central cavity or stem elongation. Postharvest Biology and Technology, 74: 11–18.

Put H.M.C. (1990): Micro-organisms from freshly harvested cut flower stems and developing during the vase life

https://doi.org/10.17221/130/2023-HORTSCI

of chrysanthemum, gerbera and rose cultivars. Scientia Horticulturae, 43: 129–144.

Qi Y., Ma L., Ghani M.I., Peng Q., Fan R., Hu X., Chen X. (2023): Effects of drought stress induced by hypertonic polyethylene glycol (PEG-6000) on *Passiflora edulis* Sims physiological properties. Plants, 12: 2296.

Rahman M.M., Ahmad S.H., Mohamed M., Ab Rahman M.Z. (2019): Improving the vase life of cut Mokara red orchid flower using leaf extracts with silver nanoparticles. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 89: 1343–1350.

Ratnayake K., Joyce D.C., Webb R.I. (2012): A convenient sample preparation protocol for scanning electron microscope examination of xylem-occluding bacterial biofilm on cut flowers and foliage. Scientia Horticulturae, 140: 12–18.

Schouten R.E., Verdonk J.C., van Meeteren U. (2018): Re-evaluating the role of bacteria in gerbera vase life. Postharvest Biology and Technology, 143: 1–12.

Serrano M., Amorós A., Pretel M.T., Martínez-Madrid M.C., Romojaro F. (2001): Preservative solutions containing boric acid delay senescence of carnation flowers. Postharvest Biology and Technology, 23: 133–142.

Shabanian S., Nasr Esfahani M., Karamian R., Tran L.P. (2019): Salicylic acid modulates cutting-induced physiological and biochemical responses to delay senescence in two gerbera cultivars. Plant Growth Regulation, 87: 245–256.

Sun Y., Liu Z., Lan G., Jiao C., Sun Y. (2019): Effect of exogenous melatonin on resistance of cucumber to downy mildew. Scientia Horticulturae, 255: 231–241.

Tiwari J.K., Munshi A.D., Kumar R., Pandey R.N., Arora A., Bhat J.S., Sureja A.K. (2010): Effect of salt stress on cucumber: Na^+–K^+ ratio, osmolyte concentration, phenols and chlorophyll content. Acta Physiologiae Plantarum, 32: 103–114.

van Doorn W.G., de Witte Y., Harkema H. (1995): Effect of high numbers of exogenous bacteria on the water relations and longevity of cut carnation flowers. Postharvest Biology and Technology, 6: 111–119.

van Doorn W.G., Zagory D., de Witte Y., Harkema H. (1991): Effects of vase-water bacteria on the senescence of cut carnation flowers. Postharvest Biology and Technology, 1: 161–168.

van Meeteren U., van Gelder H. (1999): Effect of time since harvest and handling conditions on rehydration ability of cut chrysanthemum flowers. Postharvest Biology and Technology, 16: 169–177.

Wang P., Lombi E., Sun S., Scheckel K.G., Malysheva A., McKenna B.A., Menzies N.W., Zhao F., Kopittke P.M. (2017): Characterizing the uptake, accumulation and toxicity of silver sulfide nanoparticles in plants. Environmental Science: Nano, 4: 448–460.

Williamson V.G., Joyce D.C. (2013): *Boronia heterophylla* vase life is influenced more by ethylene than by bacterial numbers or vase solution pH. Postharvest Biology and Technology, 84: 28–35.

Zhou C., Li D., Shi X., Zhang J., An Q., Wu Y., Kang L., Li J., Pan C. (2021): Nanoselenium enhanced wheat resistance to aphids by regulating biosynthesis of DIMBOA and volatile components. Journal of Agricultural and Food Chemistry, 69: 14103–14114.

Received: October 25, 2023
Accepted: March 5, 2025
Published online: September 8, 2025